Gypsum and Compost Effects on Sugarcane Root Growth, Yield, and Plant Nutrients

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ABSTRACT

Louisiana sugarcane (*Saccharum* spp.) is produced mainly on heavy-textured soils that offer less than ideal conditions for growth and function of the root system. Cultural practices that improve the soil environment could benefit sugarcane production by increasing root growth and reducing the incidence of ratoon decline. The objective of our research was to determine the effect of gypsum and composted, municipal-biosolids application on root growth, crop yields, and leaf nutrient concentrations of sugarcane grown on a silty clay loam soil. Gypsum mixed into the rows at 2.24, 4.48, and 8.96 Mg ha^{-1} did not affect ($P > 0.05$) root growth or cane and sugar yields. Likewise, both subsoil- and within-row applied compost at a rate of 44.8 Mg ha^{-1} did not affect cane or sugar yields compared with the control. Gypsum increased Ca, S, Mn, and Zn leaf concentrations, but had no effect on N, P, K, Mg, Cu, and Fe concentrations. Subsoil and within-row compost increased leaf S concentration; within-row compost increased leaf K; and subsoil compost increased leaf Zn, but reduced leaf Mn compared with the control. Compost application did not increase Mn, Cu, Fe, or Zn concentrations in sugarcane leaf tissue beyond acceptable limits. Within-row applied compost reduced ($P <$ 0.05) root surface area compared with the control, and reduced sugar yields compared with the subsoil compost treatment. This suggests that, at the compost rate used in our study, subsoil rather than within-row application of compost, is the preferred practice for sugarcane grown on this soil.

SUGARCANE (interspecific hybrids of *Saccharum* spp.) is an important agricultural commodity in Louisiana. In 2001, sugarcane was grown on 200 000 ha of land by 773 producers. An estimated 184 000 ha was harvested for sugar, with a total sugar production of 1.41 million Mg. Gross farm income from sugar and molasses was $378 million for 2001.

Most sugarcane in Louisiana is grown on heavy-textured soils that offer less than ideal conditions for growth and function of the root system. Also, the sugarcane crop cycle is frequently limited to 3 yr—a first-year crop (plant cane) and two ratoon crops—because of a complex disorder known as *ratoon decline*. Though many factors are involved, Carter (1977) suggested that excess soil moisture exacerbates ratoon decline. Hence, cultural practices that improve the soil environment could benefit root growth and sugarcane production.

One such practice is the incorporation of $CaSO_4$–$2H_2O$ (gypsum) into the soil. Gypsum application improves soil structure in heavy-textured soil, so that water infiltration and the ability of roots to penetrate the soil are enhanced. Sugarcane germination can also be promoted by increasing soil Ca (Mohandas et al., 1983). For some crops, gypsum is effective in reducing the incidence of soil-borne diseases (Kao and Ko, 1986). Moreover, mixing 11.2 and 22.4 Mg ha^{-1} of by-product gypsum into heavy-textured soils has been shown to increase sugar yields of ratoon sugarcane in Louisiana (Breithaupt et al., 1991), though it was not determined whether gypsum affected sugarcane root growth.

Other research showed a yield increase of 15% in wheat (*Triticum vulgare* Vill.) and sorghum (*Sorghum vulgare* Pers.) with gypsum addition (Thomas et al., 1995). Gypsum applied in irrigation water increased sugar yield and juice extraction percentage of sugarcane (Kumar et al., 1999). Gypsum also increased yield in corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) up to 50%. This yield response was partially attributed to higher exchangeable Ca and S, and a complementary reduction in exchangeable Al (Toma et al., 1999).

Compost improves soil structure by enhancing aggregate stability (Tate, 1987), which results in improved water holding capacity and aeration. Similarly, the beneficial effects of compost have been attributed to suppression of soil-borne diseases (Hoitink and Fahy, 1986), and to improved soil physical properties and nutrient availability (DeLuca and DeLuca, 1987). Yield increases of various crops, including sugarcane, have been reported following addition of organic amendments to soil (Bevacqua and Mellano, 1994; Hallmark et al., 1995). Horticultural crop yields and quality have also been improved with compost application (Roe et al., 1997).

With respect to plant diseases, Zhang et al. (1996) observed that compost enhanced crop resistance to several diseases, including Pythium root rot and Rhizoctinia root rot. Dissanayake and Hoy (1999) found sugarcane growth increased in *Pythium arrhenomanes*–infested soil to which organic materials had been added. The level of microbial activity resulting from the application of the organic material was an indicator of the potential for disease suppression. Compost addition was also shown to reduce the number of lesion nematodes extracted from crop roots (Abawi and Widmer, 2000).

To determine compost quality and safeness, roots and shoots of plants treated with compost can be monitored (Murillo et al., 1995). Also, compost serves as a reservoir for nutrients, such as N, P, K, and Ca, as well as micro nutrients like Cu, Fe, Mn, and Zn, and can help stabilize soil pH (Stamatiadis et al., 1999). It is, therefore, necessary to evaluate micro nutrient accumulation in crops following compost addition since this can lead to micro nutrient toxicity and decline in crop quality and yield (Rengel et al., 1999).

One problem that must be overcome if application of organic materials to large land area is to be realized is that of local supply. Also, with increasing amounts of

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Published in Agron. J. 94:1332–1336 (2002).

biosolids being composted, more application sites are needed. Therefore, assurance of compost outlets is a key component of organic disposal (Leege, 1993). Local crop land seems an ideal location, since transportation costs would be limited.

Though considerable research has been conducted on compost, most of this work has addressed the effects of compost on soil properties. The effect of compost on growth and development of agronomic crops has received less attention. To date, no published research has shown how compost application affects sugarcane root growth under field conditions.

Consequently, the objective of our research was to determine the effect of gypsum and composted, municipal-biosolids application on root growth, crop yields, and leaf nutrient concentrations of sugarcane grown on a silty clay loam soil.

MATERIALS AND METHODS

In August of 1993, a sugarcane gypsum by compost study was initiated at the LSU Agricultural Center's Iberia Research Station near Jeanerette, LA, on a Baldwin silty clay loam (fine, montmorillonitic, thermic Vertic Ochraqualf) soil. The municipal compost was produced by the Bedminster process (two parts garbage plus one part sewage sludge composted aerobically in-vessel for 3 d and cured for 6 wk), and was provided by the Vital Earth Corporation near Big Sandy, TX. The soil and compost were analyzed (Brupbacher et al., 1968; Lindsay and Norvell, 1978; Huang and Schulte, 1985) for pH and nutrient concentrations (Table 1) before the experimental treatments were applied. Soil and compost pH was determined using a 1:1 (soil/water) extraction; soil P by the Bray 2 method; exchangeable K, Ca, and Mg with 1 *M* ammonium acetate (pH 7.0); and Cu, Mn, Fe, and Zn by a 0.005 *M* solution of DTPA. Total elemental analysis of compost (for P, K, Ca, S, Mg, Cu, Mn, Fe, Zn, and Na) was determined following a nitric acid–hydrogen peroxide digestion using ICP emission spectroscopy; N was analyzed by dry combustion using a Leco nitrogen analyzer; and C by dry combustion using an Ionics carbon analyzer.

The experimental design was a Latin square split-plot with gypsum (agricultural grade, 22% Ca) rates (Table 2) as main plots and composted municipal waste treatments (Table 3) as subplots. All treatments were replicated four times. Experimental plots consisted of four 1.8 by 18.3 m rows (with four border rows on each side of the plots), with 1.8-m alleys separating the ends of each plot.

Table 1. Chemical analysis of compost and soil used in the experiment.

Variable	Compost†	Soil‡
pH	7.00	5.00
	mg kg^{-1}	
N	11 000	–
P	1 840	174
K	890	94.0
C	390 000	–
Ca	5 020	1 830
S	3 790	–
Mg	922	335
Cu	232	0.60
Mn	295	5.00
Fe	22 700	52.0
Zn	430	0.30
Na	2 290	–

† Total elemental analysis of compost.
‡ Extractable element analysis of soil.

Table 2. Effect of gypsum on root length, root width, root surface area, cane yield, and sugar yield averaged across compost treatments and harvest years.

Gypsum	Root length	Root width	Root surface area	Cane yield	Sugar yield
Mg ha^{-1}	cm		cm^2	Mg ha^{-1}	kg ha^{-1}
0	79.5a†	0.11a	434a	84.6a	8740a
2.24	84.5a	0.10a	477a	86.5a	8810a
4.48	83.7a	0.09a	446a	83.3a	9190a
8.96	77.7a	0.10a	438a	85.9a	8690a

† Values within the same column with common letters are not significantly different at $P < 0.05$.

To begin the experiment, all plots were subsoiled to a depth of 46 cm in mid-August 1993, and 44.8 Mg compost ha^{-1} (dry wt. basis) was applied in the subsoil furrow for the subsoil compost treatment (Table 3). Sugarcane rows were then rebuilt with a field cultivator. In early September 1993, all rows were opened, and 0, 2.24, 4.48, or 8.96 Mg ha^{-1} of gypsum were applied in the planting furrow, and the rows were closed. The rows were then reopened with a field cultivator (thereby mixing gypsum into the rows), and sugarcane ('Kleentek' variety LCP 82-89) was planted in mid-September using three stalks and a lap of at least two mature internodes for a seeding rate of 6730 kg ha^{-1}. After planting, 44.8 Mg ha^{-1} of compost was applied within the opened row on top of the seed cane for the within-row applied treatment (Table 3), and the rows were closed and packed to facilitate germination. All plots (and border rows between the plots) received a side-dressed blanket application in early April of 1994 and 1995 as urea (135 kg N ha^{-1}), polyphosphate (29 kg P ha^{-1}), potassium chloride (84 kg K ha^{-1}), and gypsum (27 kg S ha^{-1}). Sugarcane was grown until maturity each year using standard cultural practices.

During the peak growing period (mid-August) in 1994 and 1995, root and leaf samples were collected. Root samples were taken from each plot with a 1.8-cm diameter soil probe. Ten cores were randomly collected from each of the two center rows 45 cm perpendicular to the top of the row to a depth of 25 cm and bulked. After sample collection, roots were separated by first removing large roots by hand, then washing the remaining soil from the roots through a 40-mesh sieve. Root length, diameter, and surface area were quantified from digitized images developed with a desktop scanner (Pan and Bolton, 1991). Eight leaf tissue samples (first leaf from the top of the plant with a visible dewlap) were also collected from the two center rows of each plot at the time of root sampling, each of the 2 yr. Leaf samples were dried, ground (to pass a 40-mesh stainless steel screen), and analyzed for N, P, K, Ca, Mg, S, Mn, Cu, Fe, and Zn concentrations using the methods previously mentioned for compost analysis (Huang and Schulte, 1985).

Plots were harvested with a two-row whole stalk harvester

Table 3. Effect of compost application on root length, root width, root surface area, cane yield, and sugar yield averaged across gypsum treatments and harvest years.

Compost	Root length	Root width	Root surface area	Cane yield	Sugar yield
	cm		cm^2	Mg ha^{-1}	kg ha^{-1}
None	81.7a†	0.10a	478a	86.3a	8800ab
Subsoiled	86.4a	0.11a	450ab	86.8a	9310a
Within-row	76.2a	0.10a	417b	82.1a	8460b

† Values within the same column with common letters are not significantly different at $P < 0.05$.

Table 4. Effect of gypsum on leaf nutrient concentrations averaged across compost treatments and harvest years.

Gypsum	N	P	K	Ca	Mg	S	Mn	Cu	Fe	Zn
Mg ha^{-1}	g kg^{-1}						mg kg^{-1}			
0	15.2a†	1.7a	16.7a	4.3b	1.9a	2.0c	65.9b	5.13a	83.4a	22.7b
2.24	15.5a	1.8a	16.0a	4.9a	2.1a	2.6b	68.6b	5.25a	75.9a	22.3b
4.48	15.5a	1.8a	17.1a	5.0a	1.9a	2.9a	78.5a	5.42a	82.3a	24.9a
8.96	15.5a	1.8a	16.4a	5.0a	1.9a	2.9a	71.4ab	5.22a	72.7a	23.6ab

† Values within the same column with common letters are not significantly different at $P < 0.05$.

in mid-November of 1994 and 1995 as plant-cane and first-year ratoon crops, respectively, thus providing the sugarcane with the usual 9-mo growing season (February–November). Harvested material from each four-row subplot was weighed with a weigh rig, and a 10-stalk sample was randomly collected to determine commercially recoverable sugar (Chen and Chou, 1993). Data were analyzed using the General Linear Model (SAS Inst., 1997); where appropriate, means were separated at $P < 0.05$ using Fisher's protected LSD test.

RESULTS AND DISCUSSION

Since there were no gypsum × compost or year × treatment interactions ($P > 0.05$), all data were combined for the two experimental years. Gypsum applications had no significant ($P > 0.05$) effect on root length, root width, root surface area, cane yield, or sugar yield (Table 2). Other research using phosphogypsum on sugarcane also showed no effects on cane yield (Kumar et al., 1999). Compost applied within the row or subsoiled into the row did not affect cane or sugar yield compared with the control (Table 3). However, compost subsoiled into the row increased ($P < 0.05$) average sugar yield across the 2 yr by 850 kg ha^{-1} compared with the within-row compost treatment. Ricaud (1977) found in his work that subsoiling a light-textured soil in Louisiana to 61 cm resulted in a 19.3% increase in cane yield. It, therefore, appears that subsoiling compost down to 46 cm in our study improved soil conditions sufficiently to increase sugar yields compared with the within-row compost treatment (Table 3).

Neither compost treatment had a significant effect ($P > 0.05$) on root length or root width. However, compost applied within the row reduced ($P < 0.05$) root surface area by 61 cm^2 compared with the control (Table 3). Apparently, having compost in the root zone decreased root proliferation for the within-row treatment vs. the control, as is reflected by the trend toward shorter roots (Table 3).

Gypsum application did not affect leaf concentrations of N, P, K, Mg, Cu, or Fe, but increased leaf Ca, S, Mn, and Zn (Table 4). Previous research shows that gypsum, in the form of a commercial by-product, increased plant tissue concentrations of Ca and S (Stehouwer et al., 1996). Tissue concentration of Ca increased by 0.6, 0.7, and 0.7 g kg^{-1}, with 2.24, 4.48, and 8.96 Mg ha^{-1} of gypsum, respectively, while leaf S increased 0.6, 0.9, and 0.9 g kg^{-1} with 2.24, 4.48, and 8.96 Mg ha^{-1} of gypsum (Table 4). The 4.48 Mg ha^{-1} gypsum rate also increased leaf Mn and Zn by 12.6 and 2.2 mg kg^{-1}, respectively, compared with the control (Table 4).

Breithaupt et al. (1991) found that applying up to 22.4 Mg ha^{-1} of by-product gypsum to a heavy-textured soil did not affect ($P > 0.05$) Fe, Cu, Zn, Mn, As, Cd, Pb or Ni in sugarcane leaf tissue. Our results for Fe and Cu (Table 4) leaf concentrations support his work, but the results for Zn and Mn do not. Although we did not analyze our sugarcane leaves for As, Cd, Pb, or Ni, these elements should not have been a problem since we used agricultural-grade gypsum in our study and applied lower rates.

Leaf concentrations of N, P, Ca, Mg, Cu, and Fe were not affected by compost treatments (Table 5). Both compost treatments increased leaf S by 0.2 g kg^{-1} (Table 5). Similarly, an increase in S concentration of carrot (*Daucus carota* L.) leaves due to compost application has been reported (Warman and Harvard, 1998). Subsoil compost reduced leaf Mn by 8.5 mg kg^{-1} compared with within-row compost. Subsoil compost also reduced leaf Mn by 15.7 mg kg^{-1} and increased leaf Zn concentration by 2.6 mg kg^{-1} compared with the control, while within-row applied compost increased leaf K by 1.2 g kg^{-1} and leaf S by 0.2 g kg^{-1} over the control (Table 5). The increase in leaf K and S for the within-row compost treatment occurred although this treatment had less root surface area than the control (Table 3). This increase in leaf K and S may have been caused by the availability of K and S in the compost (Table 1).

Feagley (unpublished data, 1992) found that applying up to 224 Mg ha^{-1} of Bedminster compost (the same source of composted biosolids used in our study) did not increase As, Cd, Pb, or Ni in sugarcane leaf tissue. While we did not analyze our leaf tissue for these elements, they should not have been a problem given our lower compost application rate (44.8 Mg kg^{-1}).

Overall, gypsum and compost application at all rates and with all application methods did not increase ($P > 0.05$) cane or sugar yields in our study (Tables 2 and 3). While yield increases due to compost have been re-

Table 5. Effect of compost application on leaf nutrient concentrations averaged across gypsum treatments and harvest years.

Compost	N	P	K	Ca	Mg	S	Mn	Cu	Fe	Zn
	g kg^{-1}						mg kg^{-1}			
None	15.2a†	1.8a	15.9b	4.7a	2.0a	2.5b	78.8a	5.24a	79.0a	22.1b
Subsoiled	15.4a	1.7a	16.6ab	4.9a	2.0a	2.7a	63.1b	5.28a	78.6a	24.7a
Within-row	15.6a	1.8a	17.1a	4.9a	2.0a	2.7a	71.6a	5.24a	78.2a	23.1ab

† Values within the same column with common letters are not significantly different at $P < 0.05$.

Table 6. Recommended optimal leaf nutrient ranges and leaf nutrient concentrations of the untreated control.

Leaf nutrient	Optimal range	Untreated control
	kg ha^{-1}	
N†	20–26	15.2
P	1.8–3.0	1.8
K	11–18	15.9
Ca	2.0–5.0	4.7
S	1.4–2.0	2.5
Mg	1.0–3.5	2.0
	mg kg^{-1}	
Cu	5–15	5.24
Mn	25–400	78.8
Fe	40–250	79.0
Zn	20–100	22.1

† Mills and Jones, 1991.

ported (Bevacqua and Mellano, 1994; Roe et al., 1997), compost applications often have no effect on crop yield (Stamatiadis et al., 1999; Warman and Harvard, 1998). It is believed that the lack of yield response to gypsum and compost in our experiment was partially due to sufficient residual fertility since this was only the second time that sugarcane was grown at our test site. This is theorized because compost application has shown yield increases on similar soils where cane has grown continuously for several years (Hallmark et al., 1995). Likewise, appreciable yield responses to by-product gypsum application have been obtained in Louisiana with ratoon cane grown on heavy-textured soil (Breithaupt et al., 1991). Moreover, leaf tissue concentrations of nutrients (Tables 4 and 5) had sufficient levels for maximum cane growth (Table 6) and did not exceed the optimal range, except for S, which did not adversely affect crop yields (Table 2). Other research has indicated that residual soil fertility will reduce the benefit of compost because the nutrients that compost can supply are not then a limiting factor of yield (Stamatiadis et al., 1999).

Another possible reason for the failure to obtain a yield response to gypsum in our study is that it was only conducted for 2 yr (plant cane and first-ratoon) due to the intensive nature of measuring sugarcane root growth. It may take several years to determine the advantages of gypsum and compost application, such as increased soil tilth and reduced sugarcane diseases. The yield response obtained by Breithaupt et al. (1991) with by-product gypsum increased each year as he progressed into the three sugarcane ratoon crops. The 4-yr time period of his study apparently allowed the gypsum to have a greater effect on the soil and its consequent effects on crop growth.

CONCLUSIONS

Our results suggest that compost can be applied to sugarcane without reducing yields, and that it is better to subsoil compost into the row at the compost rate used in our study. Also, compost and gypsum did not affect plant root growth, except for decreased root surface area where compost was row-applied. Neither the gypsum rates nor the compost application rate used in our study increased nutrient metal accumulation in cane leaves beyond acceptable limits. Compost application to agricultural soil should provide better long-term fertility and lower off-site impacts compared with other means of waste disposal. Consequently, converting municipal biosolids into compost for agricultural production should be a desirable alternative to land filling or burning.

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